SUBAERIAL ALGAE OF NAVAJO NATIONAL MONUMENT, ARIZONA

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Abstract.— Samples from soils and other xeric substrates in Navajo National Monument, Navajo County, Arizona, were collected in 1978. After being moistened with deionized water for three days, these samples were analyzed for algae. Thirty algal taxa were identified. Five species of filamentous Cyanophyta comprised the majority of the biomass. Diatoms were ubiquitous in the soils although low in density. Diatom floras were very similar throughout the monument. Well-developed algal crusts were common in sites where grazing and excessive litter were absent.

Cryptogamic soil crust communities in arid regions of the world have received attention from several workers (Ali and Sandhu 1972, Anantani and Marathe 1974a, 1974b, Bischoff and Bold 1963, Cameron 1964, Chantanachat and Bold 1962, Durrell 1959, Fletcher and Martin 1948, Forest and Weston 1966, Hayek and Hulbary 1956). Such communities are variable in composition. Those best developed form crusted hummocks composed of as many as 30 to 40 species of various cryptogams including lichens, mosses, and algae (Anderson and Rushforth 1976). Under some circumstances such crusts do not develop, but algae may still be present and bind soil particles (Durrell and Shields 1961). Algal binding and crust formation protect the soils from heavy summer rains and persistent winds (Anderson and Rushforth 1976). In addition to reducing erosion and consequent leaching of minerals, nitrogen fixation by some of the blue-green algae also contributes to overall soil quality (Macgregor and Johnson 1971, Rychert and Skujins 1974, Shields and Durrell 1964, Snyder and Wullstein 1973). When crusts are disturbed by grazing or heavy human traffic, the binding of the soil is decreased and soil erosion increases (Anderson, Harper, and Rushforth in press, Loope and Gifford 1972).

Cryptogamic crusts are very widespread and important in arid regions of western North America and have been under investigation in our laboratory for several years. Anderson et al. (1976, in press) examined soil crusts throughout Utah, and discussed taxonomy, distribution, and the effects of grazing and soil quality on crust development. The present study is a continuation of our cryptogamic research and deals with the algal component of the soils and subaerial substrates of Navajo National Monument, Navajo County, Arizona.

Navajo National Monument is located in northeastern Arizona about 16 km north and west of Black Mesa and Arizona Highway 160. The principal sites of the monument are three large Indian "cliff dwellings" of the Anasazi culture. These cliff dwellings are located in three separate canyons. Betatakin and Keet Seel Canyons are part of the Tsegi Canyon complex and Inscription House is located about 32 km west of Betatakin in Nitsin Canyon. All three units lie in country dominated by pinyon-juniper communities (*Pinus edulis, Juniperus osteosperma*) growing in soil pockets associated with sandstone slickrock (Fig. 1). Within the region there exist many deep-cut canyons with high-walled sandstone cliffs, often reaching heights of 300 m above the streambeds. Springs and seeps are often encountered in these canyons, creating unique habitats that develop plant and animal communities foreign to the overall pinyon-juniper type. Aspen (*Populus tremuloides*), Gambel oak (*Quercus gambelii*), and Douglas-fir (*Pseudotsuga menziesii*) communities are present in Betatakin Canyon; oak and mixed weed communities (Fig. 2) are present in Keet Seel; and a large, heavily grazed, annual weed community (Fig. 3) exists in the Inscription House segment (Brotherson et al. 1978, Brotherson et al. in review).

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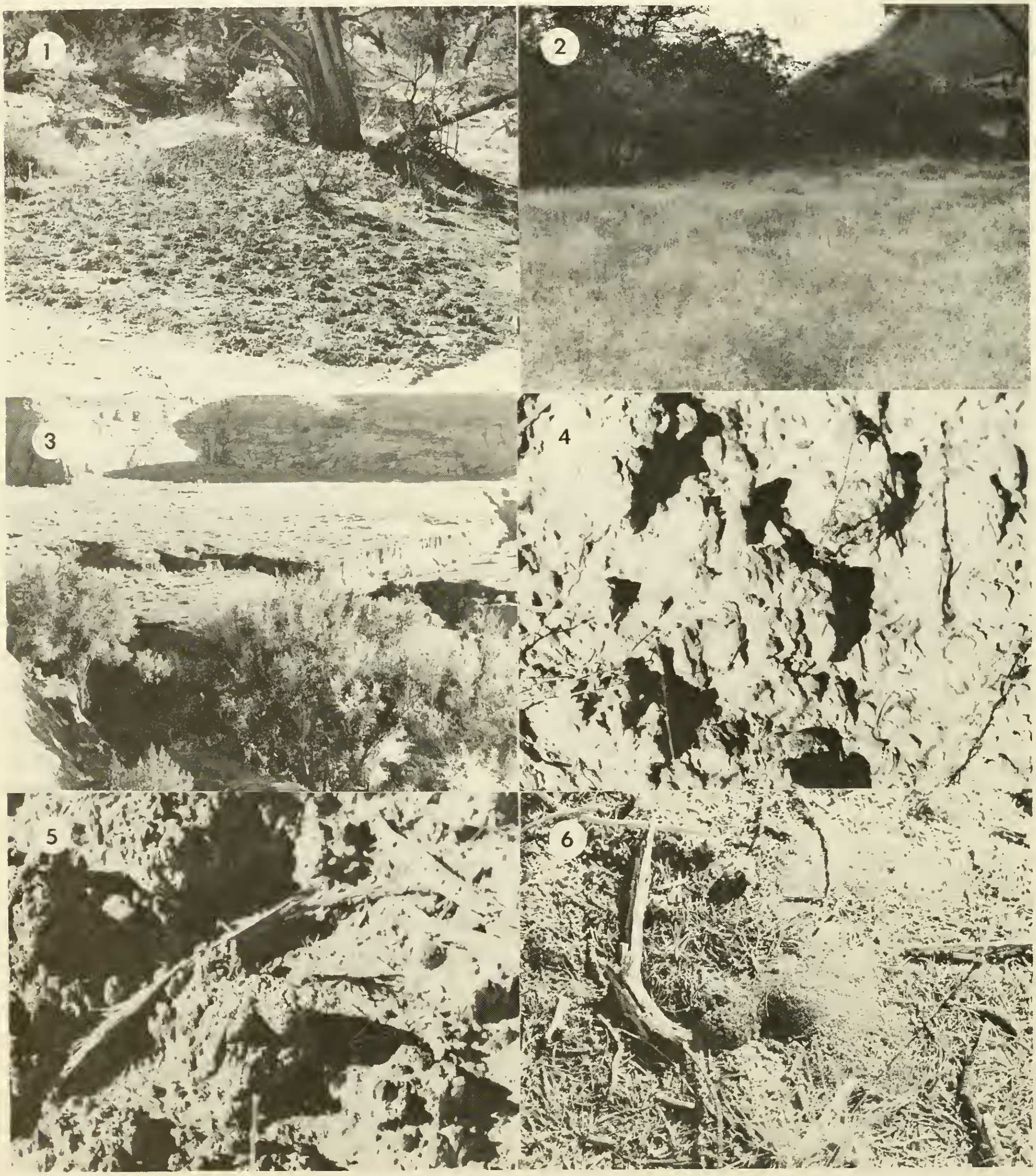
The soils of Navajo National Monument are essentially all derived from the Navajo sandstone formation. Even so, many environmental subtypes exist, providing different habitats for the development of cryptogams.

MATERIALS AND METHODS

Soil samples from the communities discussed above were obtained during the summer of 1978 by scooping approximately 200 g of soil into collection boxes. In addition mosses, lichens, and evident cryptogamic crusts (Fig. 4–6) growing on soils, rocks, and trees in the monument were also collected. These samples were subsequently moistened for 36 hours with distilled water to hydrate prominent living algae. Permanent diatom slides were later prepared using standard acid



Figs. 1–6. Collecting sites and cryptogamic crusts in Navajo National Monument, Arizona: 1, Cryptogamic soil crusts in pinyon-juniper slickrock community of Betatakin; 2, Mixed weed and oak communities of Keet Seel; 3, Annual weed community in heavily eroded Nitsin Canyon, Inscription House; 4, Algal crust; 5, Lichen crust; 6, Moss crust.

oxidation techniques and Naphrax mountant (St. Clair and Rushforth 1976). All species were studied and identified using a Zeiss RA research microscope with Nomarski interference and phase-contrast accessories.

Results and Discussion

A total of thirty algal taxa were found in the soil and rock substrates of the monument. Ten of these were blue-green algae (Cyanophyta, Fig. 7–17, 19, 20), one was a green alga (Chlorophyta, Fig. 18), and 19 were diatoms (Bacillariophyta, Fig. 21–41). These taxa are listed in Table 1 together with pertinent descriptive data. The algae most prevalent in crusted soils were all filamentous blue-green species; *Anabaena variabilis, Microcoleus vaginatus, Nostoc muscorum, Phormidium tenue,* and *Scytonema myochrous* (Table 2). These algae, particularly *M. vaginatus,* were chiefly responsible for binding the soil and producing crusts.

The best-developed crusts were those in the pinyon-juniper communities of Betatakin (Fig. 1). These soils have been protected from grazing for many years and the crusts here

Table 1. Algal taxa observed in sample collections from selected terrestrial environments of Navajo National Monument. Pertinent descriptive information for each species is included.

Cyanophyta

Anabaena variabilis Kütz. (Fig. 12): cells 4 μm wide by 2–4 μm long; heterocysts 7 μm wide by 6 μm long.

Chlorogloea fritschii Mitra (Fig. 9): cells 4–6 μm in diameter.

Chroococcus rufescens (Kütz.) Naeg. (Fig. 7): colony 10–25 μm in diameter; cells 3–11 μm in diameter.

Chroococcus turgidus (Kütz.) Naeg. (Fig. 8): colony 18–20 μm wide by 20–25 μm long; cells 6–13 μm in diameter.

Lyngbya limnetica Lemm. (Fig. 10): cells 1–3 μm wide by 1.6–6 μm long.

Microcoleus vaginatus (Vauch.) Gomont (Figs. 19, 20): colonial sheath 20–32 μm wide; trichomes 2.5–8 μm wide; cells 2–9 μm long.

Nostoc commune Vauch. (Figs. 13, 14): colony microscopic; cells 4–5 μm wide by 4–6 μm long; heterocysts 6–8 μm in diameter; akinetes 6 μm wide by 8 μm long.

Nostoc muscorum C. A. Ag. (Fig. 15): colony microscopic; cells 2.5–4 μm in diameter; heterocysts 6 μm in diameter.

Table 1 continued.

Phormidium tenue (Menegh.) Gomont (Fig. 11): cells .7–2.5 μm wide by 2–3 μm long.

Scytonema myochrous (Dillw.) C. A. Ag. (Figs. 16–17): filaments 12–15 μm wide; trichomes 6–12 μm wide; cells 3–12 μm long; heterocysts 10–12 μm wide by 7.5–10 μm long.

Chlorophyta

Unknown coccoid green alga (Fig. 18): cells spherical, 6–15 μm in diameter.

Bacillariophyta

Achnanthes linearis W. Sm. (Fig. 24): valve 2.5 μm wide by 9 μm long; striae 24 in 10 μm in the center to about 30 in 10 μm near the ends.

Achnanthes microcephala (Kütz.) Grunow: valve 3.5 μm wide by 18 μm long; striae 26–30 in 10 μm, becoming finer towards the ends.

Caloneis bacillum (Grun.) Cl. (Fig. 36): valve 3.5–4.5 μm wide by 14–24 μm long; striae 20–22 in 10 μm.

Cyclotella comta (Ehr.) Kütz. (Fig. 22): valve 30 μm in diameter; striae 10 in 10 μm.

Cymbella turgida (Greg.) Cl.: valve 10 μm wide by 33 μm long; striae 8–9 in 10 μm.

Denticula elegans f. *valida* Pedic. (Figs. 40, 41): valve 4–6 μm wide by 24–30 μm long; costae 3–4 in 10 μm; striae 20 in 10 μm.

Diatoma vulgare Bory (Fig. 26): valve 12 μm wide by 29 μm long; costae 7 in 10 μm; striae unresolved.

Hannaea arcus (Ehr.) Patr.: valve 6 μm wide; striae 12 in 10 μm (identified from broken specimens).

Hantzschia amphioxys (Ehr.) Grunow (Figs. 37–39): valve 6–9 μm wide by 29–35 μm long; fibulae 6–9 in 10 μm; striae 21–25 in 10 μm.

Melosira roeseana Rabh. (Figs. 21, 25): frustule 12–19 μm in diameter by 16–24 μm long; striae 7–9 in 10 μm.

Navicula mutica Kütz. (Figs. 27, 28): valve 6–9 μm wide by 20–29 μm long; striae 18–20 in 10 μm.

Navicula mutica var. *cohnii* (Hilse) Grunow (Fig. 29): valve 5–8 μm wide by 9–21 μm long; striae 18–20 in 10 μm.

Navicula mutica var. *undulata* (Hilse) Grunow (Fig. 30): valve 6 μm wide by 13–19 μm long; striae 16 in 10 μm.

Navicula tripunctata (O. F. Müll.) Bory (Fig. 32): valve 7 μm wide by 31 μm long; striae 12–14 in 10 μm.

Navicula tripunctata var. *schizonemoides* (V. H.) Patr. (Fig. 33): valve 7 μm wide by 36 μm long; striae 11–12 in 10 μm.

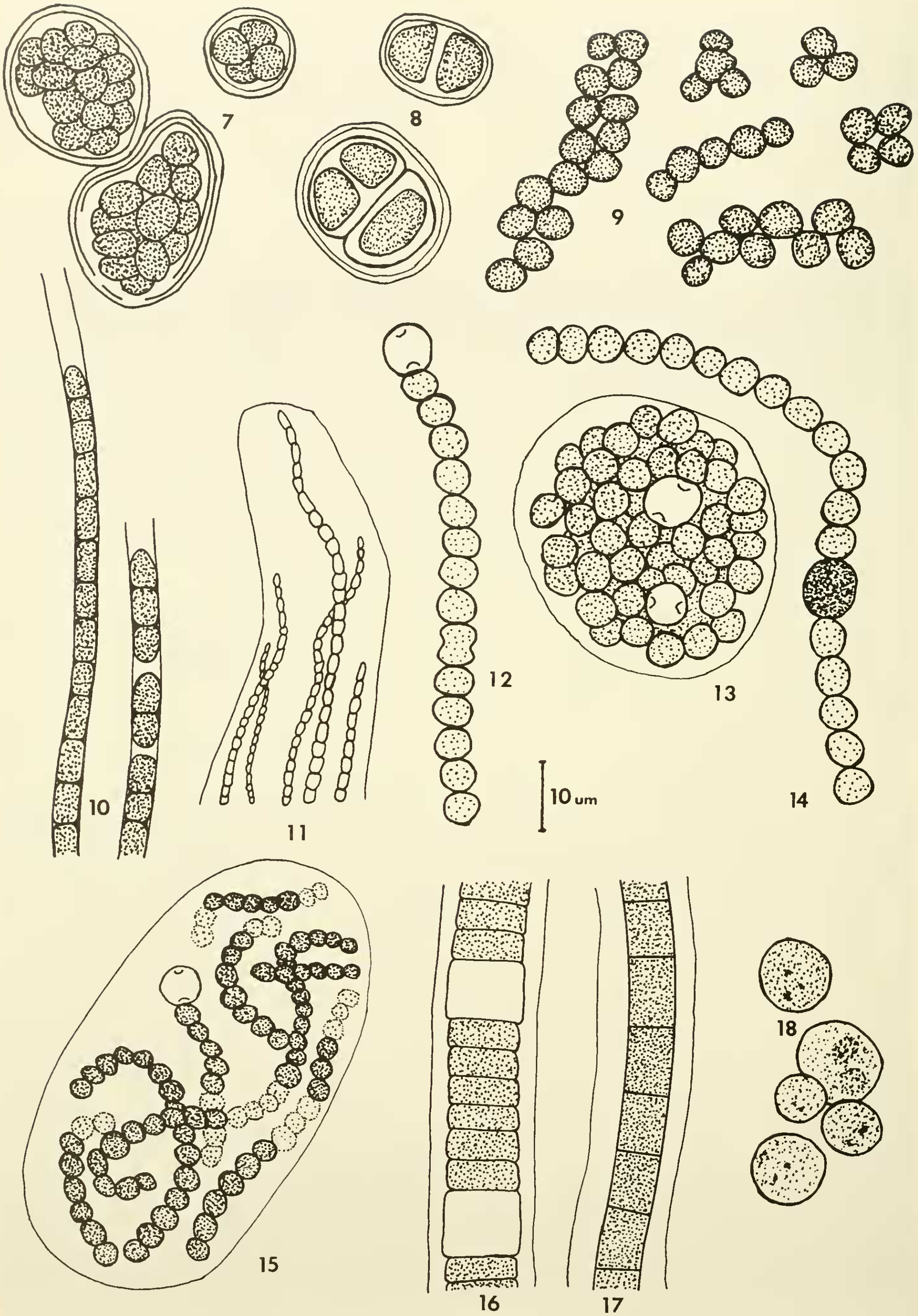
Navicula species (Fig. 31): valve 3–4 μm wide by 15–18 μm long; striae 20–22 in 10 μm in the center, becoming finer towards the ends.

Pinnularia appendiculata (C. A. Ag.) Cl. (Fig. 35): valve 4.5–6 μm wide by 21–32 μm long; striae 16–19 in 10 μm.

Pinnularia borealis Ehr. (Fig. 34): valve 7–8 μm wide by 29–45 μm long; striae 4–5 in 10 μm.

Pinnularia microstauron (Ehr.) Cl.: valve 11 μm wide by 54 μm long; striae 11 in 10 μm.

Stephanodiscus astraea var. *minutula* (Kütz.) Grunow (Fig. 23): valve 18 μm in diameter; striae 12 in 10 μm.



Figs. 7–18. Algae of xeric substrates in Navajo National Monument. All illustrations are drawn to the same scale: 7, *Chroococcus rufescens*; 8, *Chroococcus turgidus*; 9, *Chlorogloea fritschii*; 10, *Lyngbya limnetica*; 11, *Phormidium tenue*; 12, *Anabaena variabilis*; 13, 14, *Nostoc commune*; 15, *Nostoc muscorum*; 16, 17, *Scytonema myochrous*; 18, Unknown coccoid green alga.

often contain mosses and lichens in addition to algae. The oak, fir, and aspen communities of Betatakin are covered with excessive litter, which retards crust production. Due to overgrazing, crusts were absent in the Keet Seel and Inscription House areas, and serious erosion problems were evident (Fig. 3). Some crusts were found in the slickrock above Inscription House, however, where soil pockets in the rock were not subjected to grazing.

The most surprising find of this study was the widespread distribution of diatoms in the xeric habitats in the monument (Table 3). Though not a major part of the algal biomass, diatoms were found in every sample taken. The uncrusted soils of Keet Seel contained few blue-green and green algae, yet hosted a diverse diatom flora. Likewise, the lichens on the oaks in Keet Seel had diatoms associated with them, including *Hannaea arcus*, which was not seen elsewhere in the monument. The mosses and lichens on rock surfaces also supported diatom assemblages. Soils from the heavily grazed area of Inscription House had a very depressed diatom population, with only four frustules being seen after extensive examination of samples. All uncrusted soils of Betatakin, though poor in filamentous algae, contained numerous diatoms.

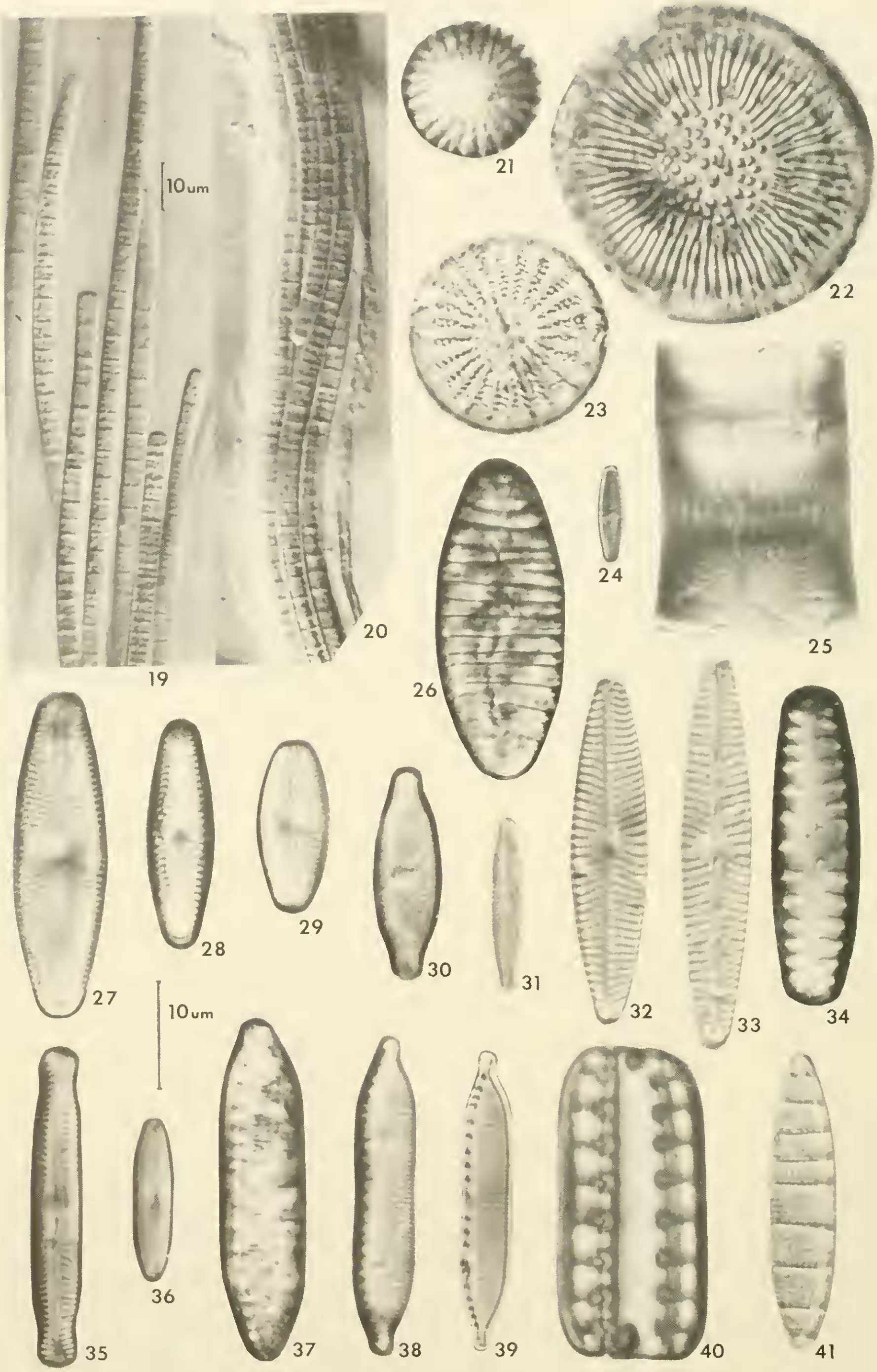
Hantzschia amphioxys was the most abundant diatom, with *Navicula mutica* var. *cohnii* being nearly as abundant (Table 3). *Navicula mutica*, *Pinnularia borealis*, and *Caloneis bacillum* were also important. The presence of two centric planktonic diatoms, *Cyclotella comta* and *Stephanodiscus astraea* var. *minutula*, was somewhat surprising, though these taxa have been reported from arid soils elsewhere (Anderson and Rushforth

Table 2. Distribution of soil nondiatoms in Navajo National Monument. Crusted soils (C), uncrusted soils (U), rocks (R), and trees (T) were sampled. Upper case letters represent common to abundant taxa and lower case letters represent rare to infrequent taxa.

Species	Betatakin	Keet Seel	Inscription House
Cyanophyta			
Anabaena variabilis Kütz.	Cu		c
Chlorogloea fritschii Mitra	c		R
Chroococcus rufescens (Kütz.) Naeg.	u		c
C. turgidus (Kütz.) Naeg.	r		cR
Lyngbya limnetica Lemm.	c		
Microcoleus vaginatus (Vauch.) Gomont	Cu		Cr
Nostoc commune Vauch.			c
N. muscorum C. A. Ag.	C		C
Phormidium tenue (Menegh.) Gomont			C
Scytonema myochrous (Dillw.) C.A. Ag.	C		Cr.
Chlorophyta			
Unknown coccoid green alga	cu	ut	r

Table 3. Distribution of soil diatoms in Navajo National Monument. Crusted soils (C), uncrusted soils (U), rocks (R), and trees (T), were sampled. Upper case letters represent relative density 20 percent or above and lower case letters represent relative density less than 20 percent.

Species	Betatakin	Keet Seel	Inscription House
Bacillariophyta			
Achnanthes linearis W. Sm.	cu		u
A. microcephala (Kütz.) Grun.	r	u	
Caloneis bacillum (Grun.) Cl.	cur		cur
Cyclotella comta (Ehr.) Kütz.	cu		
Cymbella turgida (Greg.) Cl.			r
Denticula elegans f. *valida* Pedic.	cr	u	cu
Diatoma vulgare Bory	cu		
Hannaea arcus (Ehr.) Patr.		t	
Hantzschia amphioxys (Ehr.) Grun.	CUR	UT	CUR
Melosira roeseana Rabh.	r	u	c
Navicula mutica Kütz.	cU	u	cur
N. mutica var. *cohnii* (Hilse) Grun.	Cur	U	CUR
N. mutica var. *undulata* (Hilse) Grun.			c
N. tripunctata (O. F. Mull.) Bory			u
N. tripunctata var. *schizonemoides* (V. H.) Patr.	r		
Navicula species	cur	u	u
Pinnularia appendiculata (C. A. Ag.) Cl.	ur	u	u
P. borealis Ehr.	cUr		cur
P. microstauron (Ehr.) Cl.			r
Stephanodiscus carconensis var. *pusilla* Grun.			c



Figs. 19–41. Algae of xeric substrates in Navajo National Monument. All diatom micrographs are enlarged to the same magnification: 19, 20, *Microcoleus vaginatus*; 21, *Melosira roeseana*; 22, *Cyclotella comta*; 23, *Stephanodiscus astraea* var. *minutula*; 24, *Achnanthes linearis*; 25, *Melosira roeseana*; 26, *Diatoma vulgare*; 27, 28, *Navicula mutica*; 29, *Navicula mutica* var. *cohnii*; 30, *Navicula mutica* var. *undulata*; 31, *Navicula species*; 32, *Navicula tripunctata*; 33, *Navicula tripunctata* var. *schizonemoides*; 34, *Pinnularia borealis*; 35, *Pinnularia appendiculata*; 36, *Caloneis bacillum*; 37–39, *Hantzschia amphioxys*; 40, 41, *Denticula elegans* f. *valida*.

1976). It is interesting to note that neither of these species was observed in the aquatic habitats of the monument.

The close similarity of diatom floras in the soils of the monument is good evidence that the diatoms encountered in the samples represent living communities, not incidental contaminants. Upon examining moistened crusts, living diatoms were rare. Numerous frustules, however, were found approximately 1 cm below the soil surface. It is likely that the diatoms migrate to the soil surface under favorable conditions. More work is planned to test this hypothesis. The discovery that algae grow in very arid sandy soils that show no evidence of crusting or binding has stimulated our interest in such soils, and research on the various uncrusted soil types in arid western North America is planned. Furthermore, we are currently studying the effects of grazing and compaction by humans on cryptogamic communities.

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